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Abstract

This paper provides a quantitative assessment of the relative importance of exogenous shocks related to oil price determination on countries' exchange rates and outputs within the same framework of the structural vector autoregression (VAR) model. Because we are interested in the effect of oil price changes on energy exporters and importers, we chose Australia, Canada, Japan, Norway, and the United Kingdom as the sample countries. We assume four structural shocks: (i) oil supply shocks, (ii) global demand shocks, (iii) oil price fluctuations unrelated to supply and demand, and (iv) pure exchange rate fluctuations unrelated to other structural shocks. Differing responses to structural shocks explain the correlation structure of these currencies, while pure exchange rate shocks are the main sources of exchange rate volatilities. We also examine the roles of structural shocks in explaining macro variables, taking Australia and Japan as examples. We find evidence that global demand shocks and nonfundamental oil price fluctuations have a strong impact on gross domestic product (GDP) and export growth for both countries, while pure exchange rate shocks are relatively unimportant in explaining Japan's macroeconomic variables.

Keywords: Oil prices, Exchange rates, VAR

JEL classification: F31, F41, Q43

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1 Introduction

The impact of oil prices on macroeconomic activity has been an important research theme and policy concern in many developed countries for years. The literature has mostly dealt with the effects of oil prices on countries' output and on countries' exchange rates rather separately. One strand of research mostly concerns the investigation of the relationship between oil price changes and output, which includes Hamilton (1983, 1996), Bruno and Sachs (1985), Davis and Haltiwanger (2001), and Lee and Ni (2002). More recently, strong economic growth and the increased presence of emerging countries strengthened energy demand and caused oil prices to surge. Whether such sharp increases in crude oil prices reflect global economic fundamentals or speculative concerns, which may generate asset bubbles, has been the subject of debate (Hamilton 2003, 2011; Barsky and Kilian 2004; Blanchard and Gali 2007).

Another strand of research has closely investigated the connection between oil price changes and exchange rates. For example, Amano and Norden (1998a, 1998b), Chaudhuri and Daniel (1998), Chen and Chen (2007), and Lizardo and Mollick (2010) examined the cointegration between oil prices and exchange rates. More recently, Chen, Rogoff, and Rossi (2010), and Ferraro, Rogoff, and Rossi (2015) examined whether oil prices, along with other commodity prices, could forecast future exchange rate returns.

However, when we analyze economies whose performance depends heavily on exports and imports, especially manufacturing exports and energy imports/exports, the effect of oil prices on outputs and exchange rates is inseparable. For example, it has been argued that the Japanese economy is so dependent on exports that the yen exchange rate has been a focus of attention of academics as well as policymakers since the shift to the floating exchange rate system in the early 1970s. At the same time, the Japanese economy relies heavily on energy imports; hence, an exogenous oil price increase is expected to have an unfavorable impact on business, such that it

will cause the yen exchange rate to depreciate. These observations imply that if a researcher wants to analyze the impact of exchange rate changes on the Japanese economy, one has to distinguish the yen exchange rate changes caused by oil price changes and other causes, such as foreign demand shocks or nonfundamental speculative exchange rate movements.

This paper attempts to investigate the effects of oil prices and exchange rates on the macroeconomic condition in a single framework of the structural vector autoregression (VAR) model. By extending the analytical framework developed by Lutz Kilian and his coauthors (Kilian 2009; Kilian and Park 2009) to include exchange rates in the VAR system, we identify the structural shocks behind the oil price and exchange rate movements. Because we are interested in the effect of oil price changes on developed economies with flexible exchange rates, we pick Australia, Canada, Norway, and the UK as sample countries for energy exporters. Our only energy importer sample is Japan, although we add the Euro area's 19 countries as a reference. Then, we examine the effects of these oil-price-related structural shocks on GDP and exports taking the case of Australia and Japan as examples.

The remainder of the paper is organized as follows. Section 2 presents our empirical framework to identify structural shocks by extending the framework of Kilian. In section 3, the structural VAR systems are estimated, and the structural shock series are tabulated with the data of energy-exporting and energy-importing countries. We examine the effects of structural shocks on exchange rates, including the effects of oil supply shocks, global demand shocks, market-specific oil price shocks, and exchange rate fluctuations that cannot be explained by other structural shocks, which we refer to as "pure" exchange rate shocks in this paper. It is shown that the fluctuations of the Australian dollar and the Japanese yen are largely explained by different responses by the exchange rates to the same structural shocks, while pure exchange rate shocks remain the most important sources of actual exchange rate fluctuations. Oil-price-related structural shocks are relatively unimportant for fluctuations in the Canadian dollar and the UK pound. In section

4, we examine the effects of structural shocks on GDP and export growth, concentrating on the cases of Australia and Japan. The aggregate demand shocks have a significant effect on Japanese exports and GDP, but the effect of pure exchange rate shocks is insignificant. On the other hand, Australian exports are explained by global demand shocks and market-specific demand shocks in the oil market. Section 5 provides conclusions.

2 Framework of Analysis and Data

To examine the quantitative impact of exogenous changes in crude oil prices on the country's exchange rate and economy, it is important to make an identifying assumption that distinguishes structural shocks behind the price movements (Hamilton 2003). The observed crude oil price fluctuations reflect the influence of both supply and demand, as well as the temporary demand shocks based on precautionary and/or speculative motives induced by expected future price movements. Therefore, to evaluate appropriately the effect of pure exogenous oil price changes, we must make an assumption that identifies exogenous structural shocks as being distinct from actual oil price movements.

2.1 Kilian's Structural VAR

In a series of papers (Kilian 2009; Kilian and Park 2009), Lutz Kilian addressed this issue by proposing a new measure of global real economic activity based on data on ocean freight transport fares, which are then used to identify the global demand for crude oil. To analyze the impact of exogenous shocks on the US economy, he assumed that the crude oil supply does not respond to shocks to the demand for oil within the same month.

Specifically, Kilian (2009) assumed that the current month's oil price movements were driven by three types of structural shocks. The first was

changes in global crude oil supply capacity, or exogenous shocks to the oil supply, such as those induced by coordinated OPEC production cuts. He refers to these as *oil supply shocks*. The second type of shock related to global economic conditions and is referred to as *aggregate demand shocks*. Third, there were changes in current demand based on expected future oil price fluctuations. Such demand shocks were based on precautionary and/or speculative motives; in what follows, these are referred to as crude oil *market-specific demand shocks*. For example, increased geopolitical risk in the Middle East was expected to generate precautionary demand for oil because of the increased possibility of future production cuts. Alternatively, when the global economy expanded strongly in the mid-2000s, some investors might have expected further expansion, which would have generated speculative demand for oil in anticipation of further economic expansion and crude oil price increases. These demand shocks were considered to be *oil-market-specific demand shocks*.

Kilian estimated the following three-variable VAR system for oil production, global economic activity (aggregate demand), and the oil price:

$$X_t = \alpha + \beta X_{t-1} + u_t. \quad (1)$$

$$X_t \equiv \begin{bmatrix} \text{prod}_t \\ \text{real}_t \\ \text{poil}_t \end{bmatrix}, \quad u_t \equiv \begin{bmatrix} u_t^{\text{prod}} \\ u_t^{\text{real}} \\ u_t^{\text{poil}} \end{bmatrix}, \quad \text{E} [u_t u_t'] = V.$$

Kilian imposed the following restrictions on the observed variables and structural shocks:

$$u_t = \begin{bmatrix} u_t^{\text{prod}} \\ u_t^{\text{real}} \\ u_t^{\text{poil}} \end{bmatrix} = A_0 \epsilon_t = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \epsilon_t^{SY} \\ \epsilon_t^{DE} \\ \epsilon_t^{OIL} \end{bmatrix}, \quad (2)$$

$$E [\epsilon_t \epsilon_t'] = I.$$

The variables in the VAR system and structural shocks, including additional exchange rate variables introduced in the next subsection, are summarized in Table 1.

This assumption has a number of implications for the relationship between the observed data series in the current month and the structural shocks. (i) The coefficients in the first row of A_0 , which represent the effects of structural shocks on observed oil supply, are zero, except that all implies that the change in the crude oil supply in a particular month is not affected by any other shock. (ii) The coefficients a_{21} and a_{22} in the second line of A_0 , which represent the relationship between observed real economic activity and the structural shocks, are nonzero. This implies that global real economic activity in the current month is affected by the oil supply and demand shocks but is not affected by the crude oil price in the same month ($a_{23} = 0$). (iii) All coefficients in the third row of A_0 are nonzero, which implies that the oil price in the current month is affected by all structural shocks.

[Table 1 here]

Having imposed such restrictions, Kilian (2009) estimated a monthly series for structural shocks and then converted this to quarterly data. He regressed US GDP growth on the quarterly structural shocks to investigate the effects of three different sources of oil price fluctuations: oil supply shocks, oil price changes due to aggregate demand shocks, and oil price changes due to temporary oil-market-specific demand shocks.

2.2 Extension of the System to include Foreign Exchange Rates

To investigate the effects of oil price and exchange rate on macroeconomic conditions in a single empirical framework, we extend Kilian's VAR model and add exchange rates fx_t as a fourth variable to our VAR system. This implies that we are introducing another structural shock ϵ_t^{FX} , which represents a pure foreign exchange market shock that is not contemporaneously correlated with any of the other three structural shocks. We refer to ϵ_t^{FX} as *pure exchange rate shocks*. We assume that current movements in the exchange rate are affected by all structural shocks. Thus, we impose the following restrictions on the four-variable VAR system to identify the structural shocks, as we did for the three-variable system in equation (2):

$$u_t = \begin{bmatrix} u_t^{\text{prod}} \\ u_t^{\text{real}} \\ u_t^{\text{poil}} \\ u_t^{\text{fx}} \end{bmatrix} = A_0 \epsilon_t = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \epsilon_t^{SY} \\ \epsilon_t^{DE} \\ \epsilon_t^{OIL} \\ \epsilon_t^{EX} \end{bmatrix}. \quad (3)$$

The restriction imposed by (3) implies that oil-market-specific demand shocks affect the contemporaneous exchange rate, but pure foreign exchange rate shocks do not affect the current oil price. Admittedly, this is difficult to rationalize theoretically, but preliminary analysis suggests that the shapes of the impulse response functions hardly change if the ordering of the temporary oil price shocks and exchange rate shock is switched. Thus, in what follows, our empirical results are based on estimating a VAR system that incorporates the exchange rate shock as a fourth structural shock.

2.3 Data for the Structural VAR

In the empirical analyses below, we use monthly data for the following variables. Global oil production data are taken from the website of the US Energy Information Administration. We used the index tabulated by Kilian (2009) as a measure of global real economic activity. The data come in the form of an index that Kilian constructed from data on shipping freight from Drewry Shipping Consultants, Inc., which we downloaded from his website. These two data series are identical to the data series used in various papers by Kilian and his coauthors.

Data on crude oil prices were obtained from the IMF's Primary Commodity Price Statistics and represent the average (dollar) price of North Sea Brent, West Texas Intermediate, and Dubai Fateh. Data on real effective exchange rates were obtained from the website of the Bank of International Settlements. For export and oil production, we used growth rates. We used natural log of level variables for real effective exchange rate and oil price data.

A couple of variables in our four-variable system require careful discussion. First, Kilian used real oil price data deflated by the US CPI in the structural VAR estimation. However, when one wants to apply his empirical framework to other countries, which currency should be used to measure oil price is a tricky question because we use oil price to explain both exchange rate movements and domestic real economic activity. If explaining real economic variables such as output and exports were the sole purpose of the analysis, real oil prices in local currency terms should be used.¹ As an explanatory variable for exchange rate fluctuations, nominal or real oil prices in US dollar terms make more sense because the participants in exchange rate markets are likely to use the information of energy prices quoted in

¹However, because the deflator is endogenous with respect to the domestic macroeconomy, this would apparently violate Kilian's identifying assumption in equation (2). For this reason, Fukunaga, Hirakata, and Sudo (2011) applied Kilian's analytical framework to Japan and used nominal oil price data.

US dollars. In addition, this paper investigates whether structural shocks related to oil price fluctuations can explain the correlation structure of currencies, so we would like to use the same oil price series. Hence, we decided to use real oil prices in US dollars in the following.² Specifically, our oil price measure is the price index of crude oil from IMF primary commodity prices statistics, deflated by the US CPI.

Second, Kilian (2009) emphasizes that his index of global economic activity is constructed as a measure of demand for crude oil, so the variable should not be interpreted as representing global aggregate demand in general. As an alternative to Kilian's index, we have also examined the average industrial production of OECD countries (in logs, detrended by an HP filter) as a measure of global real economic activity. In analyzing responses of domestic macro variables to structural shocks discussed in section 5, using alternative variables for global demand shocks does not make large differences in the empirical results. This is consistent with the results by Fukunaga, Hirakata, and Sudo (2011), who also used the global average of industrial production to analyze the Japanese economy's response to oil price changes. However, when we consider the historical movement of the real effective exchange rate as in section 4, average industrial production has very weak explanatory power. Because explaining the exchange rate is one of the major purposes of this paper, we use the variable tabulated by Kilian for global demand shocks in the following analyses.

²We also estimate different VAR systems using nominal and real oil prices in US dollars, and real oil prices in local currencies for Australia and Japan, then check the correlations of the same structural shocks tabulated from the different VARs. We find that almost all of the correlations are higher than 0.97. The exception is the market-specific oil demand shock tabulated by the VAR with real oil prices in Australia, but still it has the correlation of 0.92 with the same shock calculated using nominal and real oil price data in US dollars. Because we would like to use real (effective) exchange rates in our structural VAR, we decided to stick to the results using real oil prices in US dollars for the following.

3 Estimation Results for the Structural VAR

Using the data discussed in section 2, we estimated the VAR system from which we obtained impulse response functions and the corresponding structural shocks series. Because our VAR systems share same three variables—namely, oil supply growth rate, the proxy of aggregate demand shocks, and crude oil price—we expect corresponding structural shocks u_t^{prod} , u_t^{real} , u_t^{poil} from the VAR systems, including the expectation that different currencies should resemble each other. Table 2 confirms this point by presenting correlation matrices of three structural shocks. Almost all correlation coefficients are more than 0.95. Exceptions are correlations of aggregate demand shock derived from the Euro’s VAR system with non-European countries’ aggregate demand shocks. Still they are all higher than 0.93.

[Table 2 here]

3.1 Explaining the Correlation Structure of Different Currencies

Having estimated structural shocks, we first examine whether these shocks related with oil price fluctuations would help to explain the correlation structure of different currencies. For the benchmark, in Table 3, we present correlation matrices of the Australian dollar, the Canadian dollar, the Japanese yen, the Norwegian krone, and the UK pound sterling. We also include the Euro area’s 19 countries as a reference. The real effective exchange rate for the area has been calculated for the period since the early 1970s, although the Euro as a currency started around 2000. As we have already noted, Australia, Canada, Norway, and the UK are net energy exporters, and Japan and the EU are net importers. We expect the currencies of energy exporters to be positively correlated with oil prices, and the other way around for oil importers. If so, we also expect the currencies of oil exporters

and importers to be negatively correlated. The figures reported in Table 3 support our conjectures for the Australian dollar, the Canadian dollar, the Norwegian krone, and the Japanese yen. However, the UK and Euro areas are a slightly different story. The UK pound has almost no correlation with the oil price at 0.022. The Euro’s real effective exchange rate is expected to be negatively correlated with oil price, but it is actually positively correlated at 0.212.

[Table 3 here]

In Table 4, the correlations of “pure” exchange rate shocks calculated from the VAR systems are reported. Comparing corresponding numbers in Table 3 and 4, the absolute values of coefficients are clearly lower in Table 4. In other words, the effects of structural shocks related with oil price behaviors $\{u_t^{\text{prod}}, u_t^{\text{real}}, u_t^{\text{poil}}\}$ have certain roles in explaining the correlation structure of local currencies. For example, the Japanese yen’s correlation with the Australia dollar is -0.73 , but the correlation of pure exchange rate shocks is -0.24 . Similarly, the Japanese yen’s correlation with the Canadian dollar is -0.49 and the correlation of pure exchange rate shocks is -0.20 .

[Table 4 here]

To understand how oil-price-related structural shocks help to explain the correlation structure of the four currencies considered here, Figure 1 plots the impulse responses of different currencies to the same structural shocks. Panel (a) shows the responses to positive oil supply shocks. Not surprisingly, it is positive news for the Japanese yen and the Euro area countries. Conversely, it is a negative news for energy-exporting countries.

[Figure 1 here]

The impact of a positive global demand shock on energy exporters is expected to be positive. The impulse responses in Panel (b) confirm this conjecture for Australia and Canada, and to lesser extent for Norway. The impact on energy importers is not very obvious and will depend on the degree of aggregate demand shocks' exogeneity for particular countries. Perhaps the economic share of the Euro area in the world economy is too large, such that aggregate demand shock is a positive shock for this currency area. In other words, the Euro area's demand shocks consist of a significant portion of the aggregate demand shocks that we consider here. It is the other way around for Japan, and its currency depreciates when there is a positive global demand shock. These results explain why there is almost no correlation, or a slightly negative correlation, between the Euro area's and Japan's currencies.

Next, oil-market-specific price increase is expected to have a positive effect on energy-exporting countries' currencies and a negative effect on energy-importing countries' currencies. The impulse response functions of Australia, Canada, Norway (energy exporters) and Japan (importers) in Panel (c) are consistent with this conjecture. Finally, the shapes of impulse response functions for "pure" exchange rate shocks in Panel (d) are quite similar to each other. An appreciation of local currency that cannot be explained by other structural shocks tends to persist for about 12 months, then dies out.

Having observed some obvious differences in response to the same structural shocks, we would like to assess how important oil-price-related structural shocks are in explaining the fluctuations in local currencies. To answer this question, in Table 5, the results of variance decomposition for real effective exchange rates are reported. Overall results of variance decompositions are similar for Australia and Japan: oil supply shocks explain only about 4 percent of exchange rate fluctuations, while pure exchange rate shocks have maximum shares at 55% for Australia and 45% for Japan. If we consider the results more carefully, market-specific oil price shocks are much more important in explaining the Japanese yen (35%) than in explaining the Australian

dollar (19%). As a result, shares of global demand shock and pure exchange rate shock are smaller for the yen fluctuation.

[Table 5 here]

On the other hand, pure exchange rate shocks are much more important in explaining currency fluctuations for Canada (76%), the UK (88%), and the Euro area (83%). Norway comes in the middle, with the contributions from pure exchange rate shocks at 70%.

3.2 Historical Evolution of Structural Shocks

The empirical results in section 3.1 suggest that contributions of structural shocks related to oil price fluctuations are relatively unimportant for the Canadian dollar and mostly negligible for the UK and the Euro area. Hence, in the remaining part of this paper, we concentrate on the cases of Australia (an energy exporter) and Japan (an energy importer).

Figure 2 shows quarterly data for the structural shock series, taking the four-quarter moving average. As we noted in section 3.1, because the first three variables in the VAR are identical for the Australian and the Japanese VAR systems, the structural shocks tabulated from the two VAR systems are highly correlated with each other. Thus, the structural shocks from the two VARs are shown in one graph for the first three variables in the system.

[Figure 2 here]

There are several notable features in historical evolutions in structural shocks. From the first graph, it is clear that the size of the oil supply shocks diminish in the latter sample period, particularly after 2002. Conversely,

positive demand shocks are more prominent in the latter sample period. Specifically, there are consecutive positive demand shocks from 2002 to the first half of 2008. For market-specific oil price shocks, we do not find clear changes in the average size of the shocks. However, the average level of the shocks is apparently higher in the later sample after 1999.

Next, let us consider the exchange rate shocks. In his original analysis, Kilian did not use the variable that we have labeled as the pure *exchange rate shock*, and so this variable warrants detailed discussion. The variable *exchange rate shock* represents real effective exchange rate fluctuations that cannot be explained by other structural shocks; i.e., *oil supply shocks*, *global aggregate demand shocks*, and *oil-market-specific demand shocks*. As shown in Table 4, Australia's and Japan's structural exchange rate shocks are slightly negatively correlated with the correlation coefficient at -0.236 . Therefore, they are presented in two different graphs in Figure 2.

The graph for Japan's structural exchange rate shocks suggests that there were consecutive negative exchange rate shocks in the first half of the 1980s. Therefore, the sharp increase in the value of the yen following the Plaza Accord of September 1985 can be interpreted as a recovery in its value following the excessive depreciation of the first half of the 1980s.

However, the role of pure exchange rate shocks is more significant in the first half of 1990. This is consistent with the fact that Japan's real effective exchange rate recorded its historical peak around 1993–1995. Another period in which positive exchange rate shocks were significant is from late 2008 to mid-2012. Again, this is consistent with the fact that the Japanese economy suffered from the relative increase in the value of the yen and the stagnation of exports during this period. This period corresponds to Governor Shirakawa's tenure at the Bank of Japan, when he maintained a relatively tight monetary policy position while the central banks in other developed economies adopted aggressive monetary easing to cope with the risk of financial crises. It is important, and would be interesting to exam-

ine, whether this was the result of the difference in monetary policy or the difference in other fundamental conditions of the macroeconomy. However, it is beyond the scope of this paper, and we will leave it as a subject for future research.

3.3 Historical Decomposition for Exchange Rates

In section 3.1, we have already discussed that differences in responses to oil-price-related structural shocks will explain why Australia's and Japan's real effective exchange rates tend to move in opposite directions, using the impulse response functions reported in Figure 1. To investigate this problem further, Figure 3 presents historical counterfactual decompositions of Australia's and Japan's real effective exchange rates.³ Each line bearing the name of a shock series is the real effective exchange rate counterfactual associated with only the corresponding structural shocks.

[Figure 3]

We reconfirm from these graphs that the real exchange rates of the two countries actually move in opposite directions most of the time. Turning our attention to the contributions of structural shocks, oil supply shocks ϵ_t^{SY} have mostly negligible impacts on exchange rates, except in the first half of the 1980s when the oil price increased the Australian dollar and decreased the Japanese yen.

Two exchange rates responded oppositely to aggregate demand shocks and market-specific oil price shocks. As pointed out in our discussion about the historical evolution of structural shocks in Figure 2, from 2002 to the first half of 2008, there were successive positive global aggregate demand

³See Rossi and Zubairy (2011) for the example of historical decomposition in the macroeconomic context.

shocks. Corresponding results in the historical decompositions in Figure 3 imply that Australia’s currency appreciated and Japan’s currency depreciated in response to these positive demand shocks ϵ_t^{DE} in the mid-2000s. Similarly, market-specific oil price shocks ϵ_t^{OIL} were mostly positive in the 2000s, except for the brief period around the collapse of Lehman Brothers and toward the end of the sample in the second half of 2014. This means that oil price shocks’ contribution increased the Australian currency and decreased the Japanese currency in the second half of the 2000s and the early 2010s. Hence, opposite responses to aggregate demand shocks and oil-market-specific demand shocks provide a partial explanation for the negative correlation between Australia’s and Japan’s real effective exchange rates.

4 Output and Export Response to Structural Shocks

To analyze the effect of structural shocks on aggregate economy, we regress quarterly GDP and export growth on our estimated structural shock series. Specifically, we estimate the following regression:

$$y_t = \delta + \sum_{i=0}^{24} \psi_i \hat{\epsilon}_{t-i} + \nu_t, \quad (4)$$

where y_t represents quarterly growth rates of GDP and exports, and $\hat{\epsilon}_{t-i} = \begin{bmatrix} \epsilon_{t-i}^{SY} & \epsilon_{t-i}^{DE} & \epsilon_{t-i}^{OIL} & \epsilon_{t-i}^{EX} \end{bmatrix}'$ is the vector of structural shocks at time t estimated using restriction (3).

However, our regression relates quarterly output data to explanatory variables on the right-hand side that are structural shocks converted from monthly data to quarterly data. Hence, by construction, the response of GDP growth or export growth y_{t+1} to the structural shocks at time t is:

$$\frac{dy_{t+1}}{d\widehat{\epsilon}_t^k}, \quad (5)$$

where the k subscript denotes the four individual structural shocks, SY (crude oil supply shock), DE (global demand shock), OIL (market-specific shocks in the crude oil market), and EX (shock unique to the exchange rate market). If each variable is stationary, for t :

$$\frac{dy_t}{d\widehat{\epsilon}_{t-1}^k} = \frac{dy_{t+1}}{d\widehat{\epsilon}_t^k} = \psi_{ik}, \quad (6)$$

which can be used to calculate (cumulative) impulse responses to structural shocks.

Figure 4 shows the impulse responses of real quarterly growth rates of GDP and exports for Australia and Japan. Table 6 summarizes the main results illustrated by Figure 4. Our ensuing discussion of the impulse responses is based on Table 6.

[Insert Table 6 and Figure 4 here]

According to Table 6, the oil supply shock had no statistically significant effect on both GDP and export growth for both Australia and Japan. This result is consistent with previous results by Kilian (2009) on the US and Fukunaga, Hirakata, and Sudo (2011) on Japan. The aggregate demand shock has a significant effect on Australian exports, Japanese exports, and the Japanese GDP but not on Australian GDP. Market-specific shocks in the oil market significantly increase Australian exports but do not affect other variables. Finally, the exchange rate shock only affects Australian exports negatively for the very short run. From the graphs, exchange rate shocks

seem to have a negative impact on the Japanese GDP in the short run and a persistent negative impact on Japanese exports. However, those effects are statistically insignificant.

The results of counterfactual historical decomposition reported in the previous section indicate that the contributions of global demand shock to exchange rate movements are more pronounced in the sample after the late 1990s. In particular, the decline in the real effective exchange rate for the yen from the early 2000s to the first half of 2008 will be largely explained by the successive global demand shocks. The result that Japanese GDP growth is affected by global demand but not by exchange rates in Figure 4 is consistent with such comovements of exchange rates and demand shocks.

For Australia, the fact that market-specific oil price shocks increase exports suggests that when oil prices go up, they induce the appreciation of energy prices in general. Therefore, Australia can enjoy the increase in energy exports too.

5 Conclusions

In this paper, we extended the structural VAR model of Kilian and his coauthors to provide a quantitative assessment of the relative importance of exogenous shocks related to oil price determination on countries' exchange rates and outputs within the same framework. We assume four structural shocks: oil supply shock, global demand shock, oil-market-specific demand shock, and pure exchange rate shock.

Such an empirical framework is used to explain the fluctuations and the correlation structure of the Australian dollar, the Canadian dollar, the Japanese yen, the Norwegian krone, and the UK pound sterling. We find that the structural shocks related to oil price fluctuations are important in

explaining Australia's and Japan's currencies. These are relatively unimportant in explaining the fluctuations of the Canadian dollar and particularly the UK pound. Australia's and Canada's currencies respond positively to global demand shocks and to oil-market-specific demand shocks, while Japan's exchange rate responds in opposite ways. Such differing responses to the same structural shocks will explain why the currencies of two energy-exporting countries and Japan are negatively correlated. On the other hand, in explaining exchange rate volatilities, pure exchange rate shocks are most important sources of shocks for all countries.

In explaining macro variables, we find the evidence that global demand shocks and oil-market-specific demand shocks have strong impact on GDP and export growth, while pure exchange rate shocks are relatively unimportant in explaining Japan's macroeconomic variables. The results that Japanese GDP growth is affected by global demand, but not by "pure" exchange rate shocks, are consistent with the fact that the yen depreciates in response to positive global demand shocks.

Historically, the importance of exchange rate shocks has been largely emphasized in macroeconomic policy discussions for economies that depend heavily on manufacturing exports and energy imports/exports. Our empirical results suggest that the importance of the exchange rate has been exaggerated. Other economic factors, such as the level of global economic activity and the oil price, have had large impacts on Australian and Japanese exports.

Some important issues have been left as subjects for future research. First, the list of countries that depend heavily on manufacturing exports and energy exports/imports includes many countries other than the four countries that we have considered in this paper. Applying the framework developed here to other countries will be an interesting extension. Second, we have refrained from discussing the possibility of structural change in the relationship between structural shocks and macro variables. Admittedly,

the concern is about the potential instability of the relationship between exchange rates and manufacturing exports, because there is substantial evidence of changing the exchange rate pass-through and the offshore production shift.

Third, output variation in close substitutes of crude oil such as shale gas has a large potential impact on oil price formation. In particular, the increase in shale gas production in North America in the 2000s would have caused structural change between the market oil price and the structural shocks. Additionally, it could have affected the oil price through market participants' expectations of the future oil price. In this paper's context, this transmission channel will be captured by the variation in "oil-market-specific price shocks."

Both oil-market-specific demand shocks and pure exchange rate shocks are fluctuations in the corresponding variables that cannot be explained by other variables in the VAR system. However, there is the possibility that the VAR was not specified correctly and/or that some variable was missing from the estimated system and has explanatory power for the oil price or exchange rates. We leave the discussion about oil price shocks to other experts.⁴ For the exchange rate, we obviously ignore the possibility that monetary variables affect real effective exchange rates, at least for the short run. Toward the end of section 3.2, we suggested that persistent positive yen exchange rate shocks from late 2008 to mid-2012 might be explained by the Bank of Japan's monetary policy without any concrete evidence. Examining economic forces behind large pure exchange rate shocks should be an important subject of our future research.

⁴See, for example, Kilian (2014).

6 Appendix

6.1 Impulse Response Functions

Figure A1 presents the impulse response functions of the VAR system corresponding to equation (3) for Australia and Japan. Since the first three variables in the VAR are identical, including the ordering, the impulse response functions in the upper-right nine panels are mostly identical for both the Australian and the Japanese VAR systems. So when we discuss the first three variables in the VAR system for the first three structural shocks, we treat the impulse responses from two countries' systems as identical.

The first column shows the responses of oil production to the structural shocks. In the top panel, the oil supply shock has a large immediate effect on oil production. After six months, it decreases to about one-third of the initial response and remains statistically significant. The second panel from the top shows the oil production response to global demand shock. Oil production does not respond immediately nor sharply. But, the increase is statistically significant for the period about six to twelve months after the initial shock. In the third and the bottom panel, the effects of both the temporary oil price shock and exchange rate shock on crude oil production are negligible and insignificant.

[Figure A1 here]

In the second column, we find that global real economic activity is hardly affected by the crude oil supply shock. By contrast, the global aggregate demand shock has a clear and persistent impact on global economic activity. The oil market specific demand shock also has a temporary positive effect on global economic activity that lasts for up to six months. In the third column, the aggregate demand shock and the oil market specific demand shock in particular have large positive impacts on oil prices. Oil prices are

hardly affected by the oil supply shock, but this may be because no large oil supply shocks occurred during our sample period.

The fourth column shows the responses of real effective exchange rates to the structural shocks. Exchange rates' impulse response functions from Australian data in panel (1) and from Japanese data in panel (2) exhibit stark contrasts. The effects of oil supply shocks on real effective exchange rates are statistically insignificant for both countries. On the other hand, a positive global demand shocks slightly, but persistently and statistically significantly, increase Australia's exchange rate. Both global demand shocks and oil market specific demand shocks do not make statistically significant impacts on the yen exchange rate, they both tend to lower the value of the yen. By contrast, Australia's currency significantly appreciates for several months, though the effect vanishes in the long run. Reasonably, a temporary exchange rate shock has a large and persistent effect on the real effective exchange rate in both countries' cases.

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Table 1

Variables in the Structural VAR

prod_t	Growth rate of world crude oil production
real_t	Proxy for global real economic activity (Kilian)
poil_t	Crude oil price
fx_t	Real effective exchange rate

Structural Shocks

ϵ_t^{SY}	Oil supply shock
ϵ_t^{DE}	Aggregate demand shock
ϵ_t^{OIL}	oil-market-specific demand shock
ϵ_t^{FX}	Pure exchange rate shock

Table 2**Correlations of the Structural Shocks Calculated Using VAR Systems Including Local Currencies**

(i) Oil supply shock

	CAN	JAP	NOR	UK	Euro
AUS	0.971	0.980	0.966	0.956	0.978
CAN	–	0.976	0.958	0.952	0.970
JAP	–	–	0.967	0.965	0.982
NOR	–	–	–	0.950	0.970
UK	–	–	–	–	0.965

(ii) Aggregate demand shock

	CAN	JAP	NOR	UK	Euro
AUS	0.970	0.960	0.969	0.952	0.933
CAN	–	0.955	0.967	0.950	0.932
JAP	–	–	0.975	0.950	0.941
NOR	–	–	–	0.966	0.949
UK	–	–	–	–	0.941

(iii) Oil-market-specific shock

	CAN	JAP	NOR	UK	Euro
AUS	0.961	0.957	0.956	0.948	0.952
CAN	–	0.961	0.965	0.957	0.958
JAP	–	–	0.967	0.963	0.965
NOR	–	–	–	0.963	0.965
UK	–	–	–	–	0.966

Table 3
Correlations of Real Effective Exchange Rates and Oil Prices
(in natural logs)

	CAN	JAP	NOR	UK	Euro
AUS	0.786	-0.728	0.651	0.060	0.159
CAN	–	-0.488	0.664	-0.142	0.368
JAP	–	–	-0.452	-0.298	-0.016
NOR	–	–	–	0.005	0.117
UK	–	–	–	–	-0.602

	AUS	CAN	JAP	NOR	UK	Euro
OIL	0.827	0.624	-0.734	0.588	0.022	0.212

Table 4
Correlations of “Pure” Exchange Rate Shocks

	CAN	JAP	NOR	UK	Euro
AUS	0.397	-0.236	0.107	-0.039	-0.083
CAN	–	-0.198	0.146	0.000	0.010
JAP	–	–	-0.116	-0.129	0.001
NOR	–	–	–	-0.051	0.056
UK	–	–	–	–	-0.298

Table 5
Variance Decomposition for Real Effective Exchange Rates

Australia				Canada			
ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}	ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}
4.3(%)	21.6	18.7	55.4	4.1	16.4	4.1	75.5
Japan				Norway			
ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}	ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}
4.2	16.0	35.0	44.8	7.0	8.2	15.0	69.9
UK				Euro			
ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}	ϵ_t^{SY}	ϵ_t^{DE}	ϵ_t^{OIL}	ϵ_t^{EX}
3.1	6.4	2.7	87.8	8.4	8.0	0.8	82.7

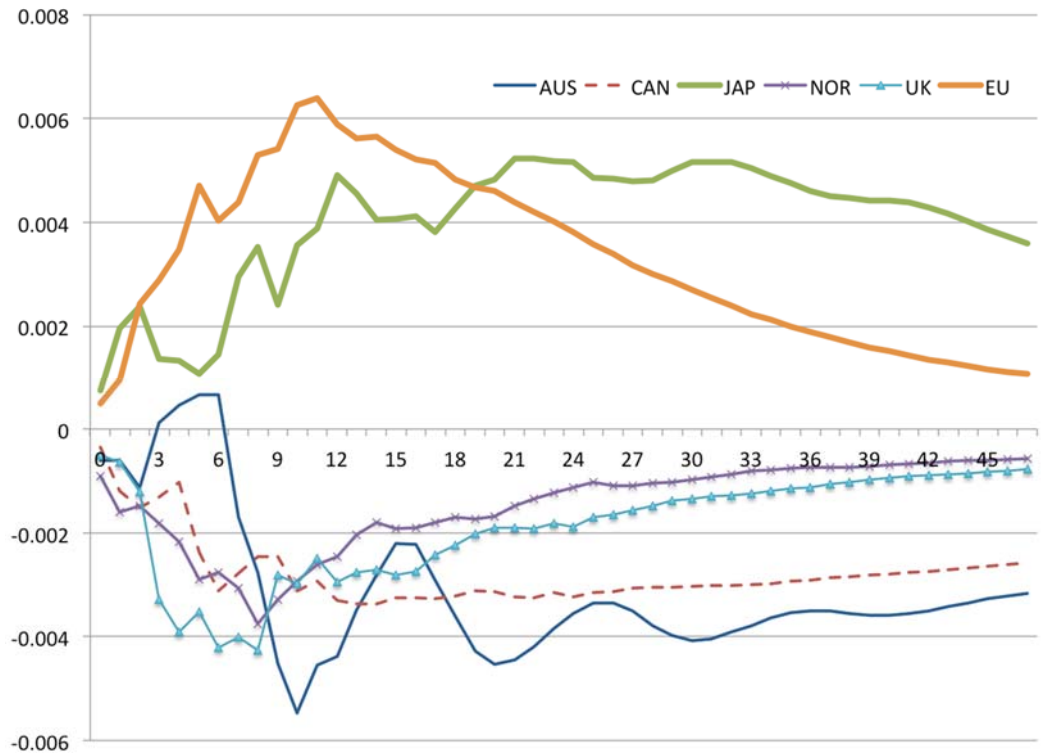
Table 6
Responses of GDP and Export Growth to Structural Shocks

		Oil supply	Demand	Oil price	FX
		ϵ_{t-i}^{SY}	ϵ_{t-i}^{DE}	ϵ_{t-i}^{OIL}	ϵ_{t-i}^{EX}
Australia	GDP	—	—	—	—
	Exports	—	up	up	down
Japan	GDP	—	up	—	—
	Exports	—	up	—	—

Note: “Up” denotes an impulse response to a particular shock that is significant at the 10% level for at least two consecutive quarters out of the 12 that we examined. Similarly, “down” indicates that the variable decreases.

Figure 1
Responses of Real Exchange Rates to Structural Shocks

(a) Responses to oil supply shocks



(b) Responses to aggregate demand shocks

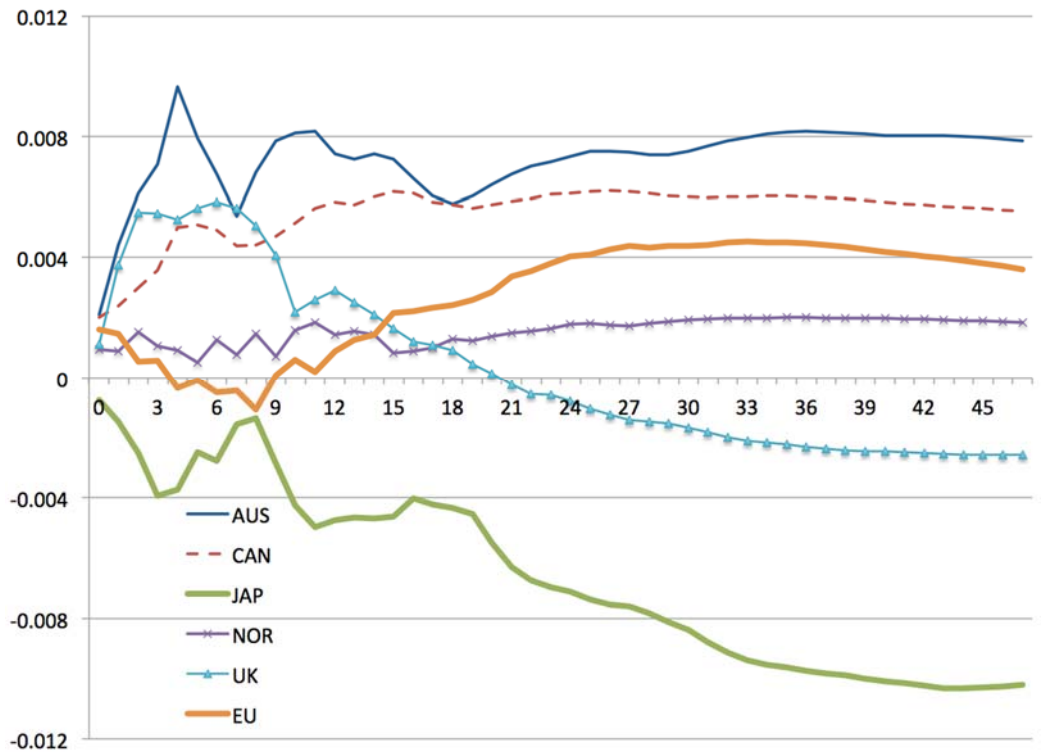
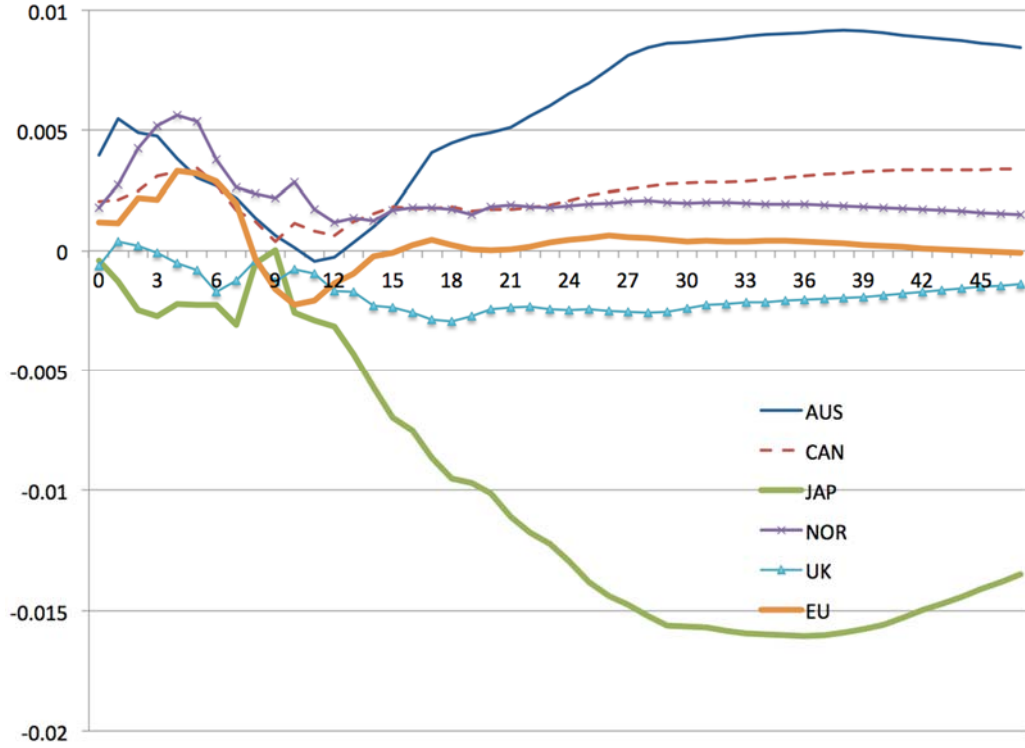


Figure 1 (continued)

(c) Responses to oil-market-specific price shocks



(d) Responses to “pure” exchange rate shocks

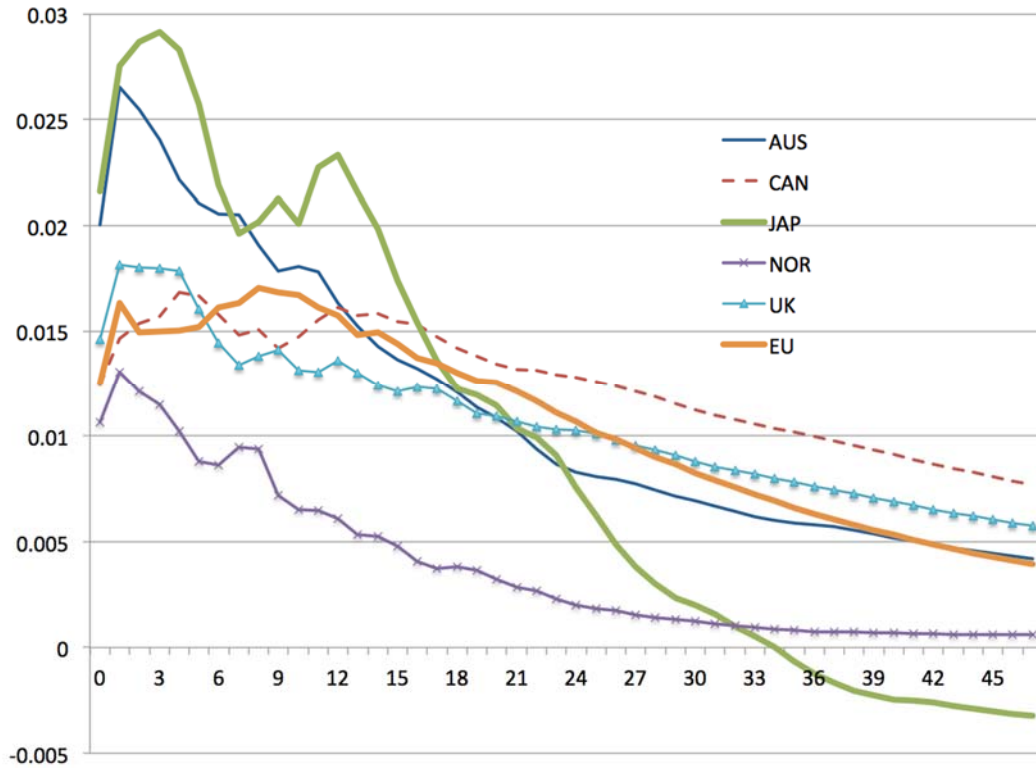
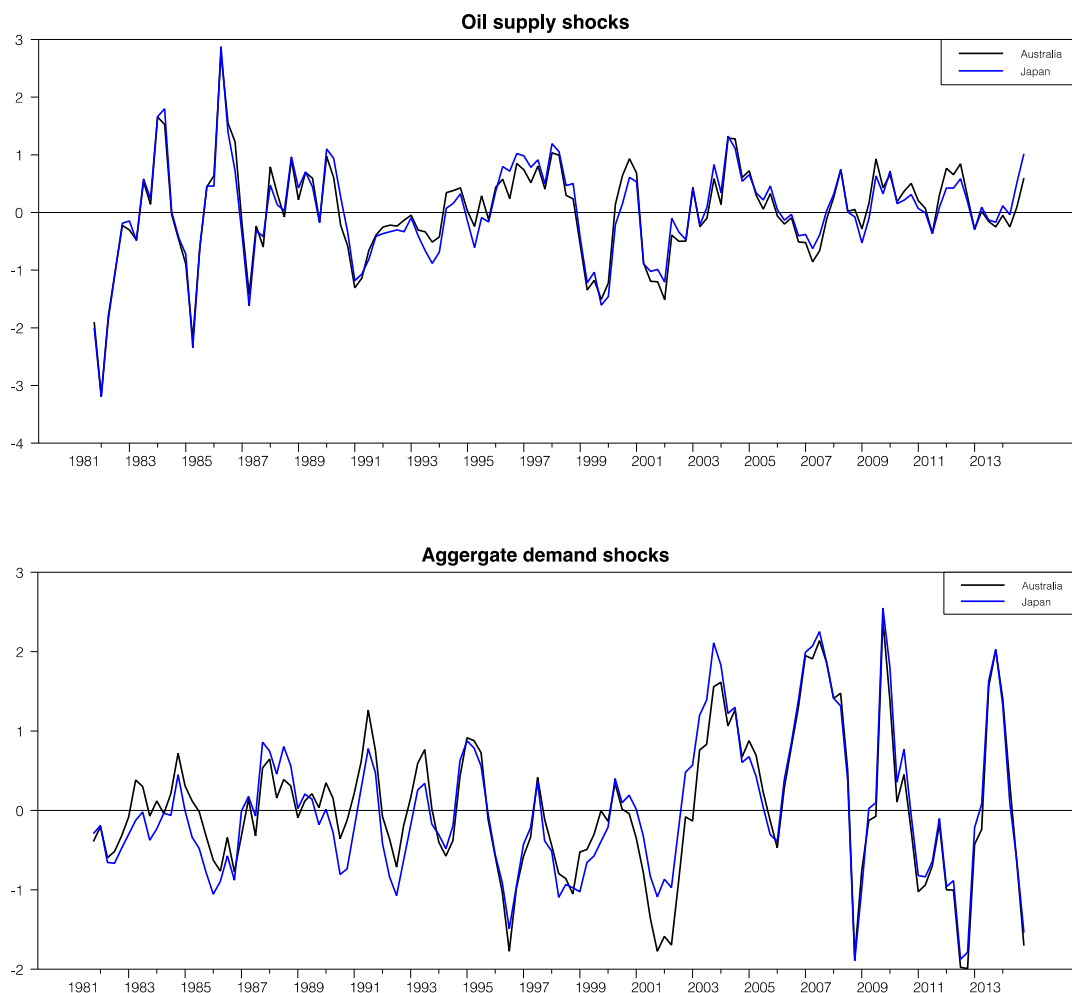


Figure 2
Historical Evolution of the Structural Shocks: Australia and Japan



The four-quarter moving average of structural shock series converted from monthly to quarterly data is shown. The structural shocks from two VARs are shown in one graph for the first three variables in the system. Exchange rate shocks are shown in separate graphs.

Figure 2 (continued)

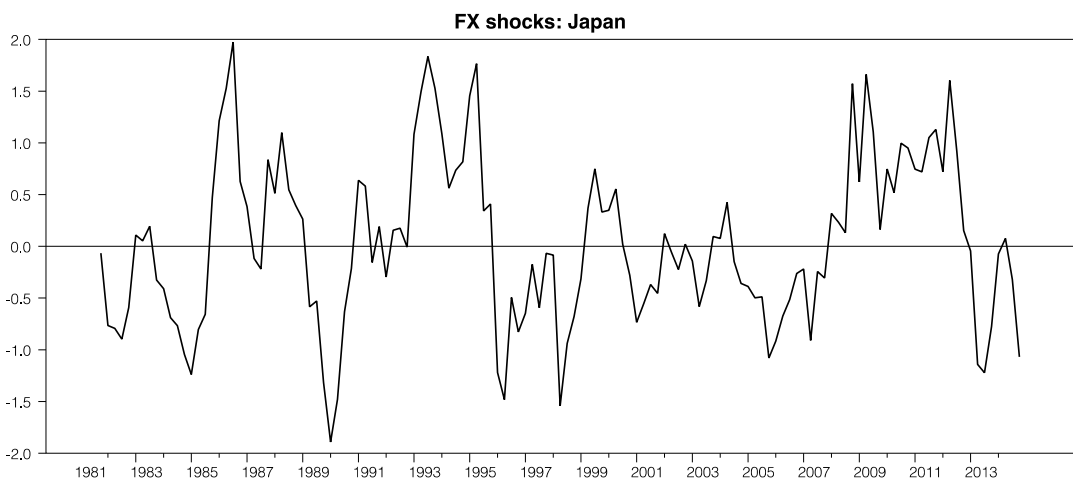
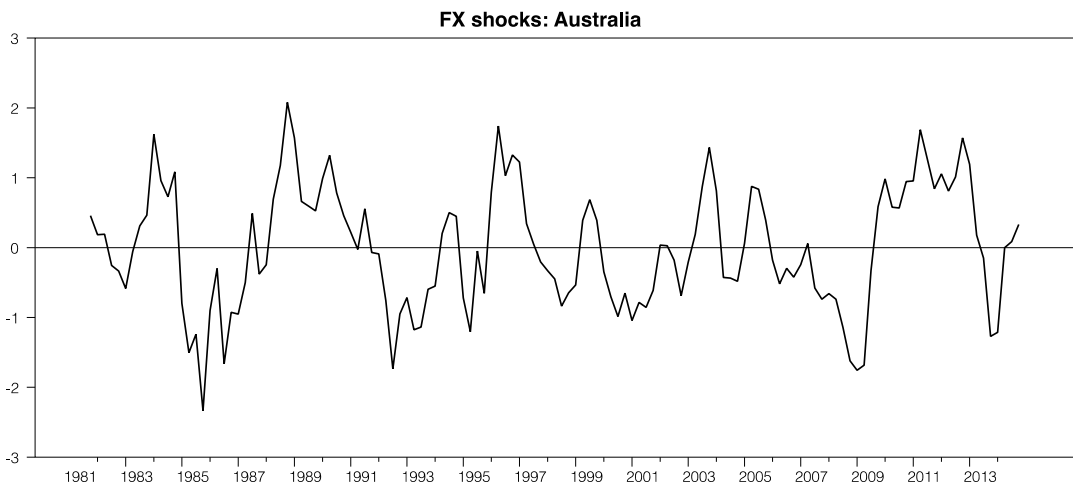
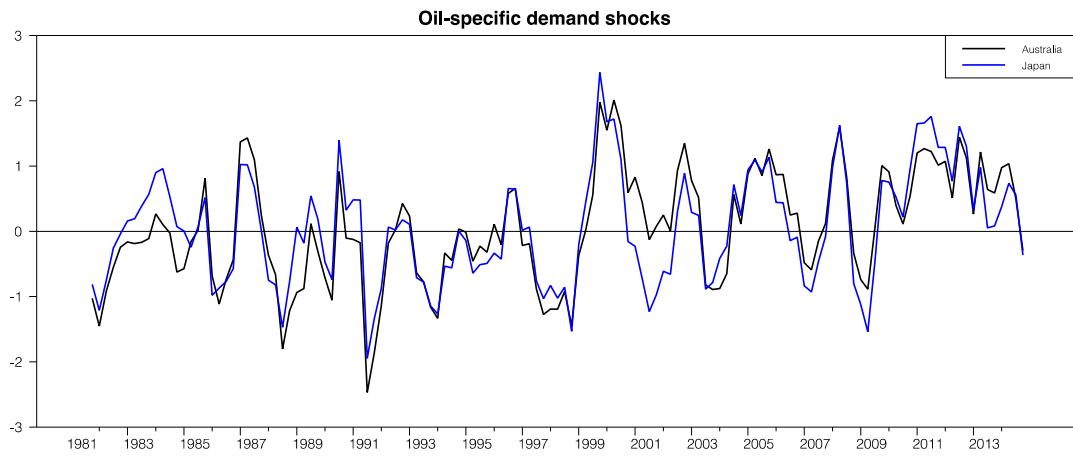


Figure 3
Historical Counterfactual Decomposition of
Real Effective Exchange Rates: Australia and Japan

(1) Australia

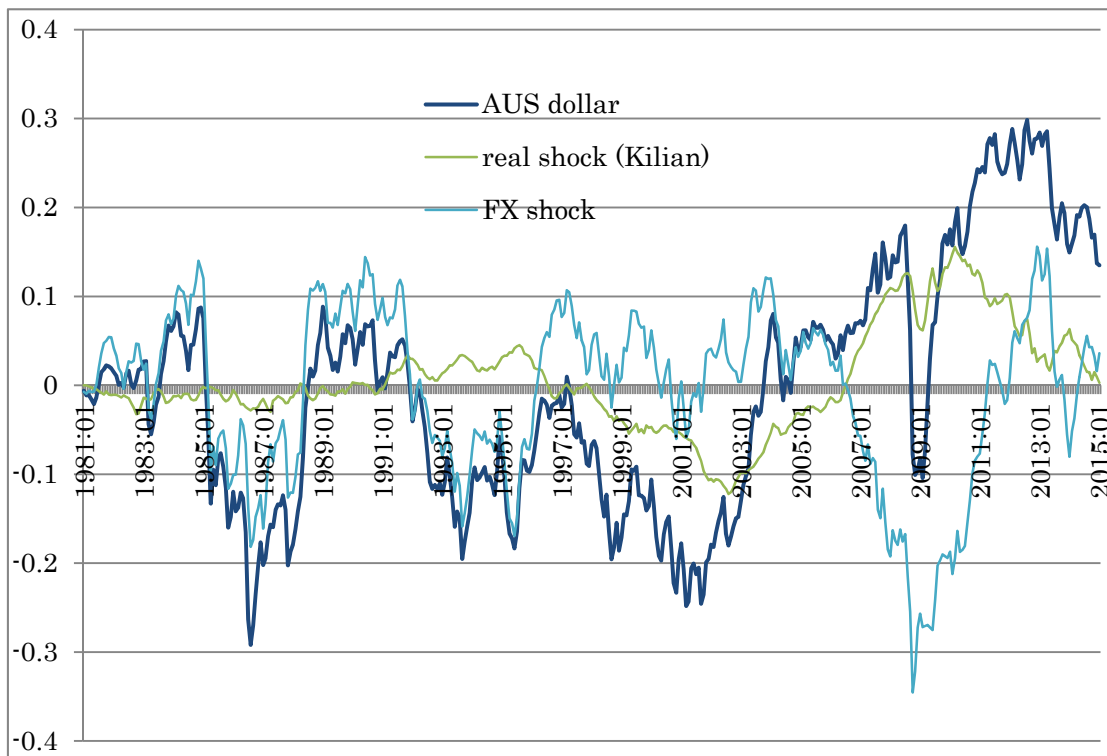
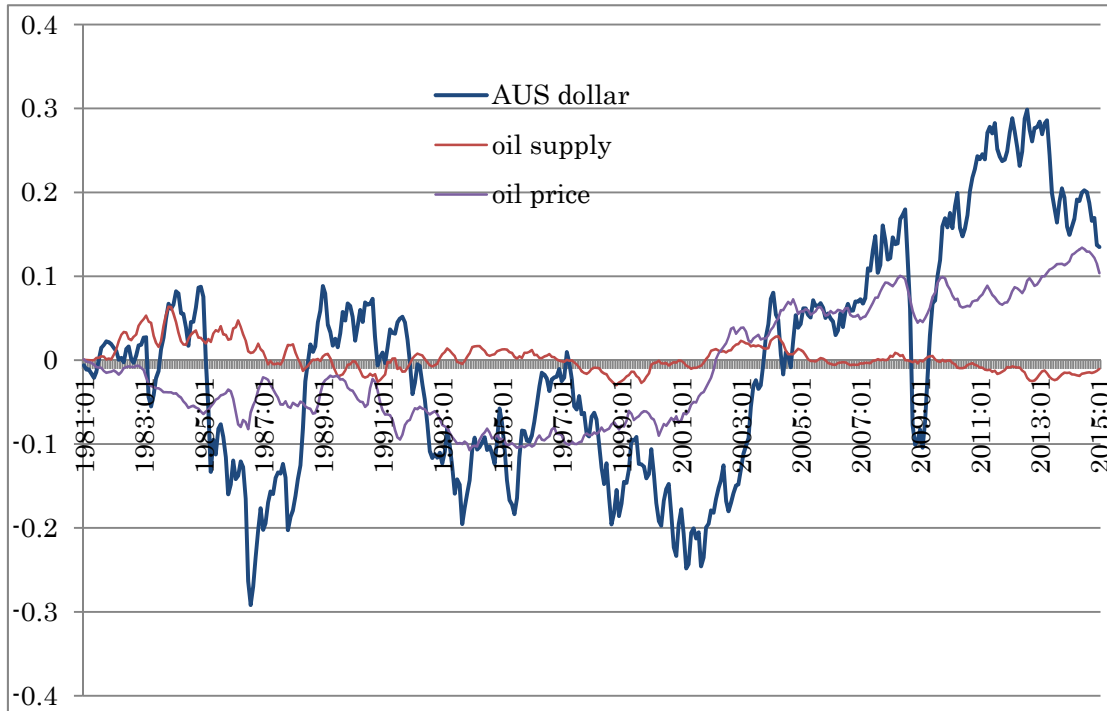


Figure 3 (continued)

(2) Japan

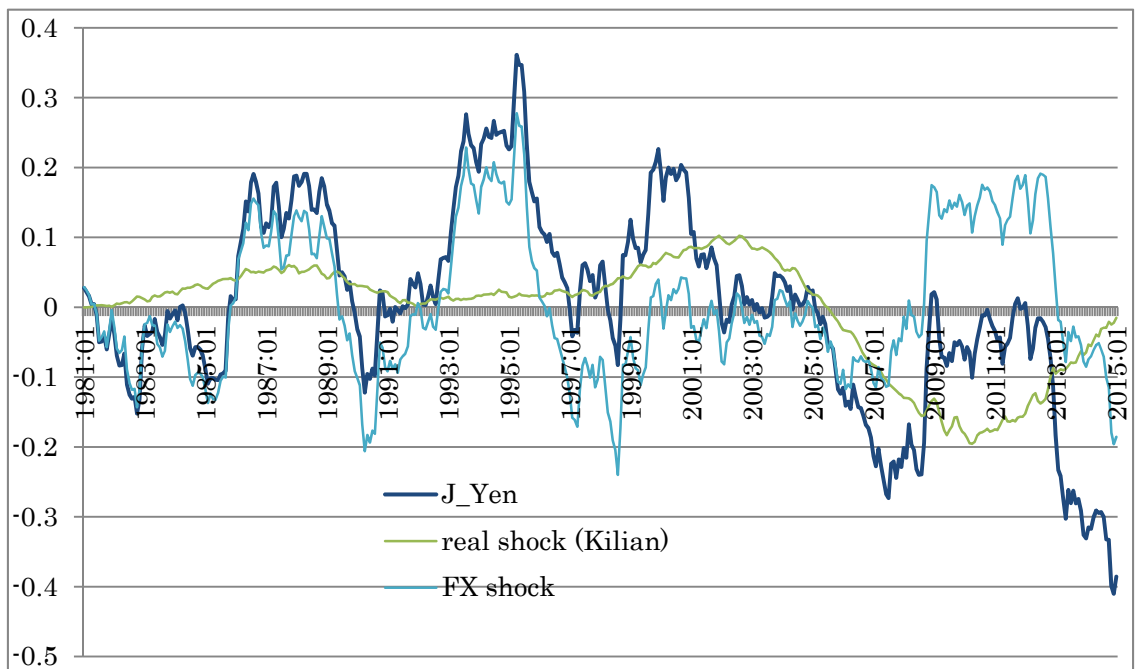
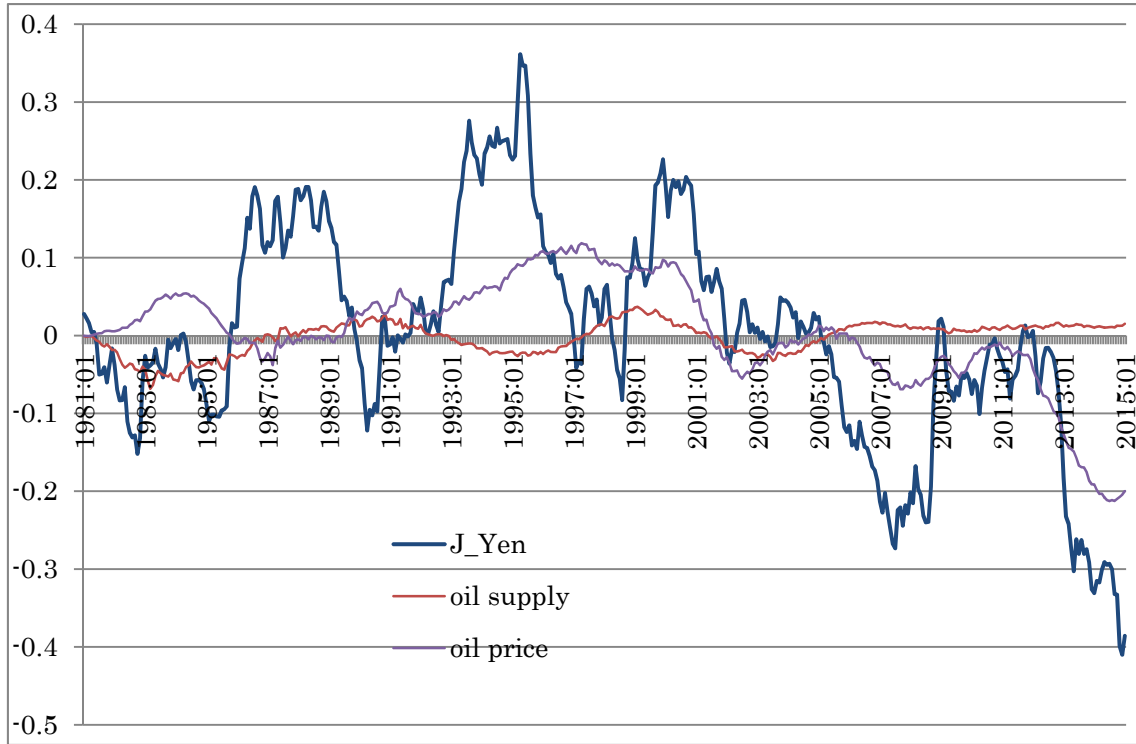


Figure 4
 Responses of GDP and Export Growth Rates to
 One-standard-deviation Structural Shocks: Australia and Japan

(1) Australia

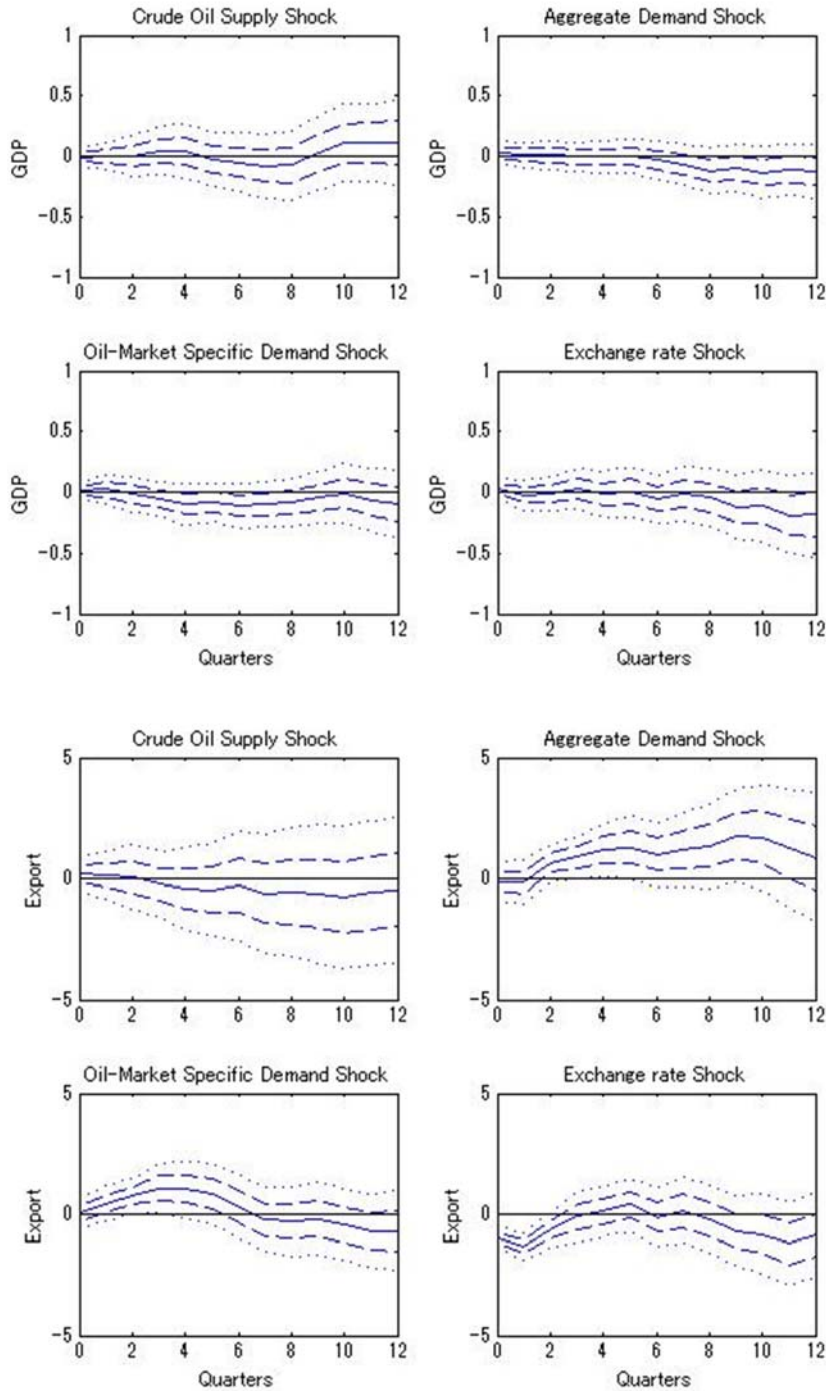


Figure 4 (continued)

(2) JAPAN

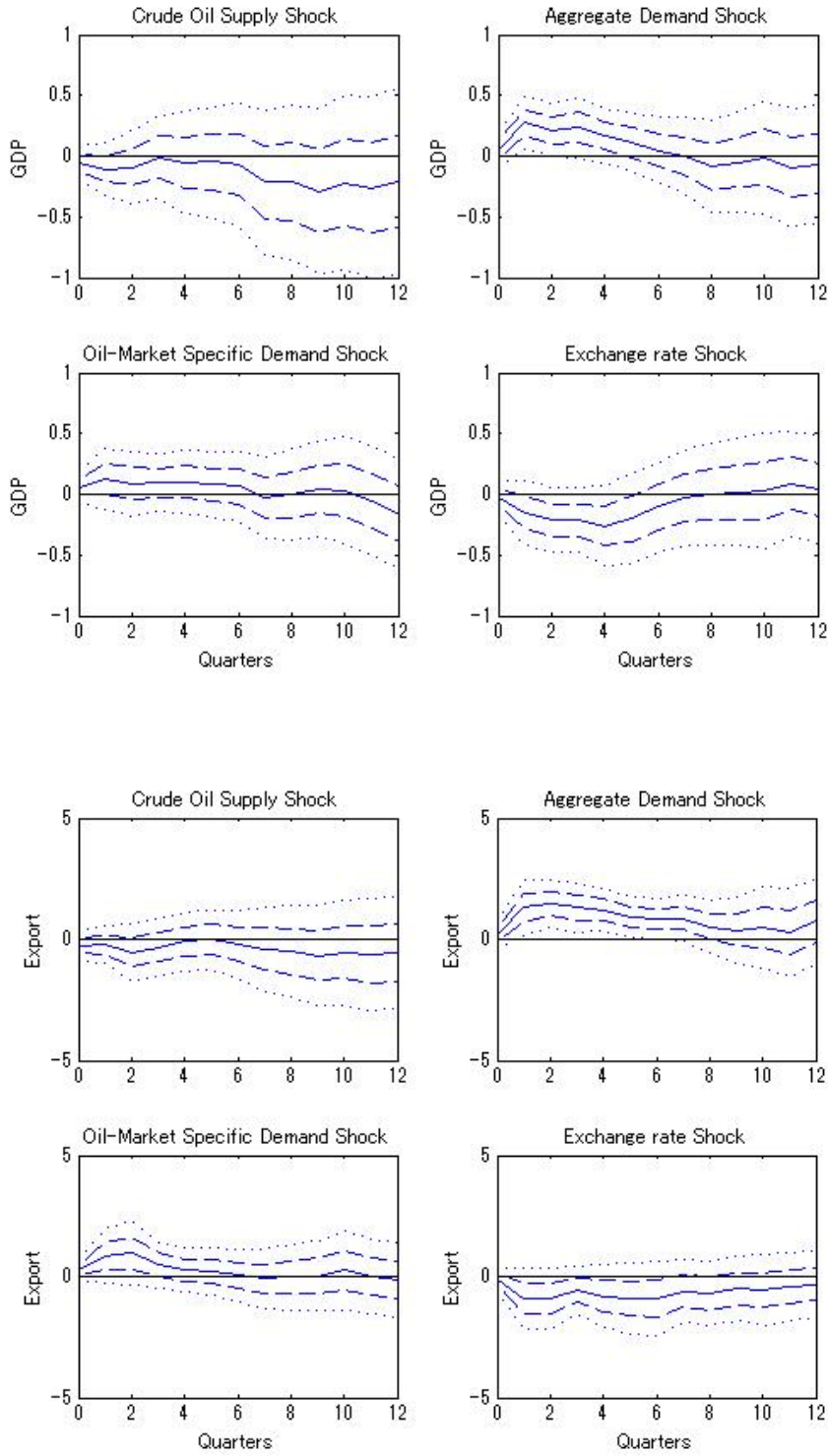
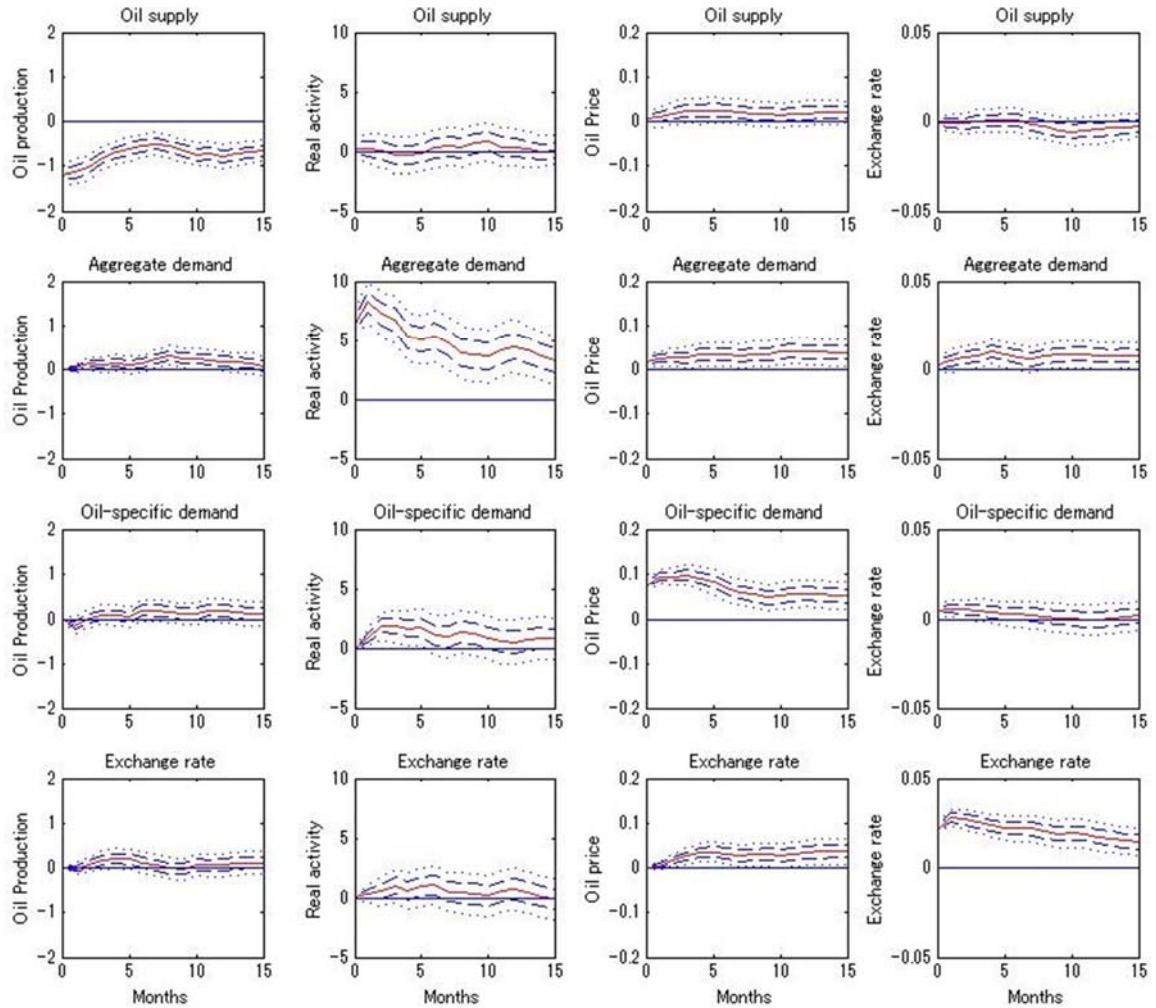


Figure A1
 Impulse Response Functions of the Structural VAR:
 Australia and Japan

(1) Australia



Note: ± 1 standard error bounds are shown in coarse dashed lines and ± 2 standard error bounds are shown in fine dashed lines above and below impulse responses.

Figure A1 (continued):

(2) Japan

